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The Electromechanical Design of a Spring Pin Based WLCSP Contact Engine and it's Effect on Signal Fidelity.

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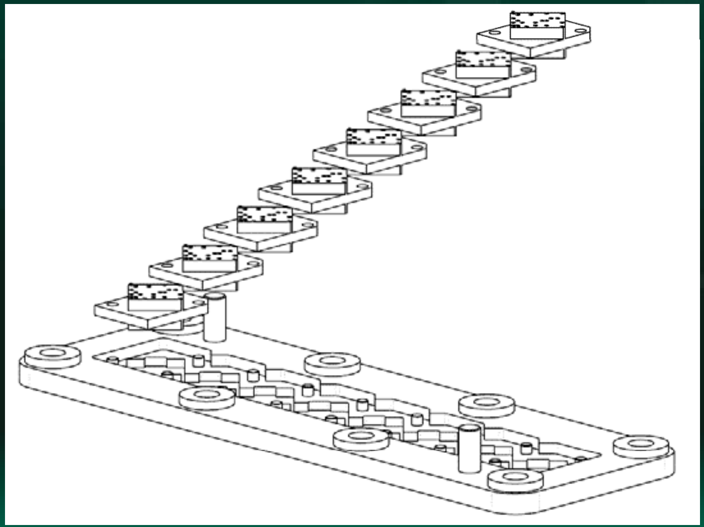
Introduction

Goal

- **To better understand the electrical implications of the mechanical features in WLCSP spring pin based contact engines.**



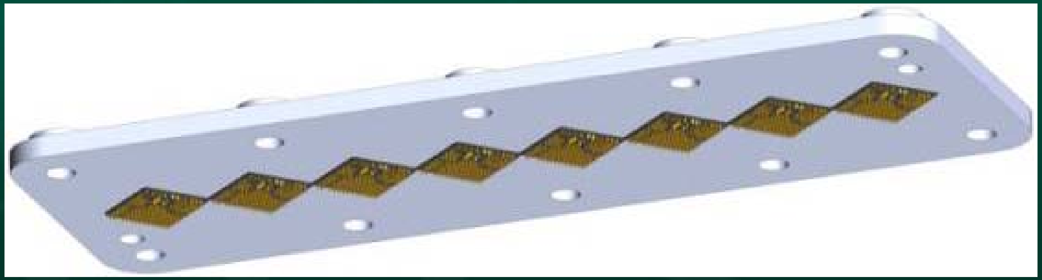
Agenda

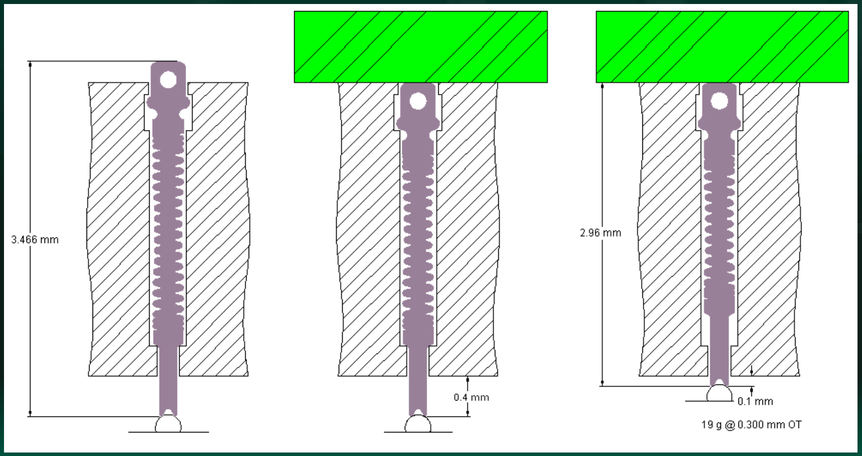
- What is a Spring Pin Based WLCSP Contact Engine?
- Spring Pin Circuit Performance Requirements.
- Electrical Performance - Datasheets.
- Contact Circuit Equivalent Models.
- Analytical Analysis.
- Techniques For Model Fitting.
- Pin Placement in Contact Engine.

Introduction

What is a Spring Pin Based WLCSP Contact Engine?

For the purposes of this presentation a WLCSP contact engine is a spring pin type of contact in a dielectric housing for wafer level probing using pitches ranging from 300 μm to 500 μm.





Spring Pin Circuit Performance Needs

- **Power Delivery.**
  - Low Inductance to avoid ground bounce and power rail collapse.
- **Signal Integrity.**
  - Digital
    - High Speed Edges
  - RF
    - Controlled Impedance

Data Sheet Comparisons

- **A survey of datasheets shows an inconsistant reporting of electromechanical parameters.**

- **At a minimum these mechanical factors need to be known for electrical characterization.**
  - Length, Pitch, Radius, Conductivity and Dielectric Constant.

- **From these parameters all of the following can be modeled.**
  - Loop, Partial and Mutual Inductance.
  - Shunt capacitance or Mutual capacitance.
  - S-Parameters, Phase Delay, Band Width, Rise Time and Isolation.

Data sheet values

- **The methods used to extract, calculate or measure the lumped element electrical parameters are important in understanding how to use them in practice or when comparing pins.**

- **Lumped element equivalent model parameters are only valid when the physical Length << $\lambda/10$.**

- **When the Length is not << $\lambda/10$ microwave models should be used.**

Inductance

The lowest self inductance does not mean highest bandwidth.

High bandwidth is obtained by controlled impedance.

Inductance

- **Loop inductance is the only inductance parameter that can be measured directly.**

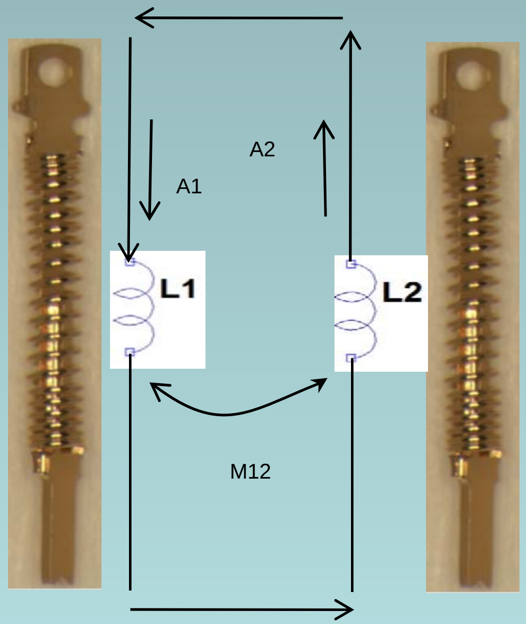
- **Self and mutual Inductance are only mathematical concepts that cannot be measured directly.**
  - The inductance of a single pin can be calculated and uniquely assigned to a pin.

Capacitance and Resistance

- **Capacitance can be modeled from mesurements or simulation.**
  - This can be bounded by calculation as well.
- **Resistance**
  - Is the smallest factor to model and the easiest to calculate.

Spring Pin Partial Inductance

- **Partial Inductance may be uniquely calculated in piecewise segments using the magnetic vector potential.**

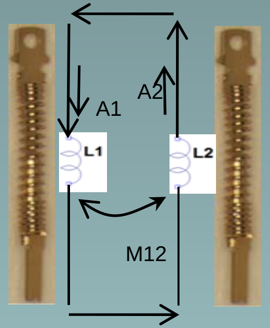


$$L_{loop} = \frac{\psi}{I} = \frac{\oint_s B \bullet ds}{I} = \frac{\int_s (\nabla \times A) \bullet ds}{I} = \frac{\int_c A \bullet dl}{I}$$

$$L_{loop} = \frac{\int_{c_1} A \bullet dl}{I_1} + \frac{\int_{c_2} A \bullet dl}{I_2} + \ldots + \frac{\int_{c_n} A \bullet dl}{I_n}$$

$$M_{ij} = \frac{\int_{c_j} A \bullet dl}{I_j} \qquad L_{partial} = \frac{\int_{c_i} A \bullet dl}{I_i}$$

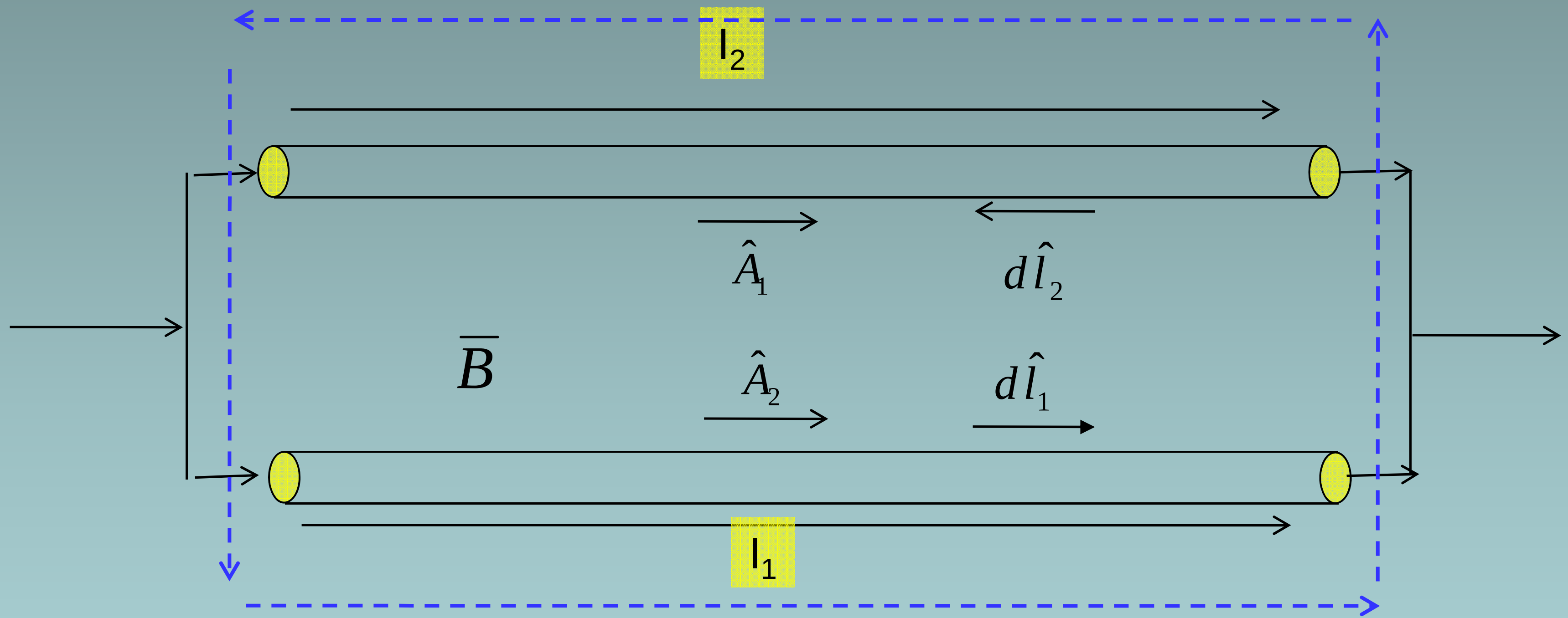
Spring Pin Partial Inductance and Partial Mutual Inductance Between Two Straight Parallel Segments



$$L_{partial} = \frac{\mu_o l}{2\pi}\left[\ln\left(\frac{l}{r_w} + \sqrt{\left(\frac{l}{r_w}\right)^2 + 1}\right) - \sqrt{\left(\frac{r_w}{l}\right)^2 + 1} + \frac{r_w}{l}\right]$$

$$M_{partial} = \frac{\mu_o l}{2\pi}\left[\ln\left(\frac{l}{d + r_w} + \sqrt{\left(\frac{l}{d + r_w}\right)^2 + 1}\right) - \sqrt{\left(\frac{d + r_w}{l}\right)^2 + 1} + \frac{d + r_w}{l}\right]$$

Mutual Inductance and the Integration Path for Two Pins Carrying a Shared Current.



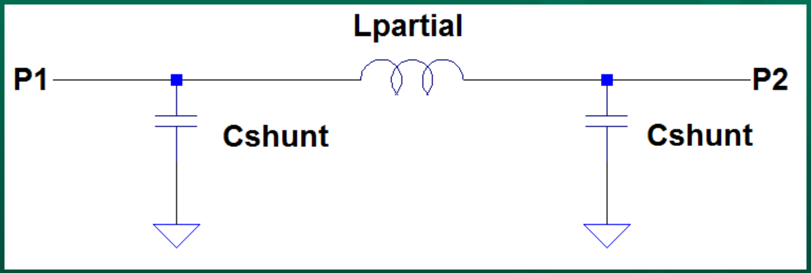
The sign of the mutal inductance coefficients comes from the dot product of $\hat{A}_j \bullet d\hat{l}_i$

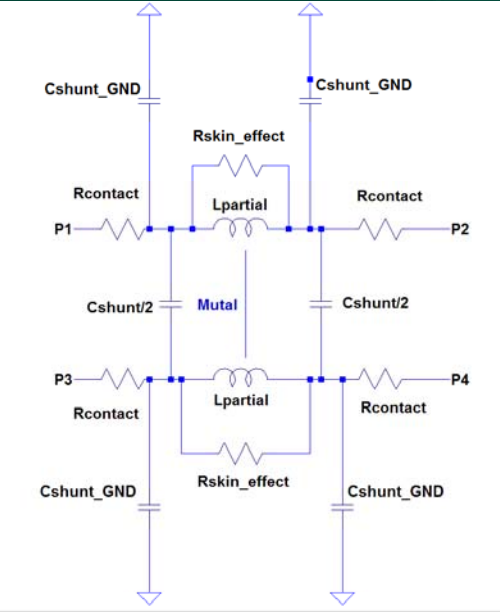
Model Topologies

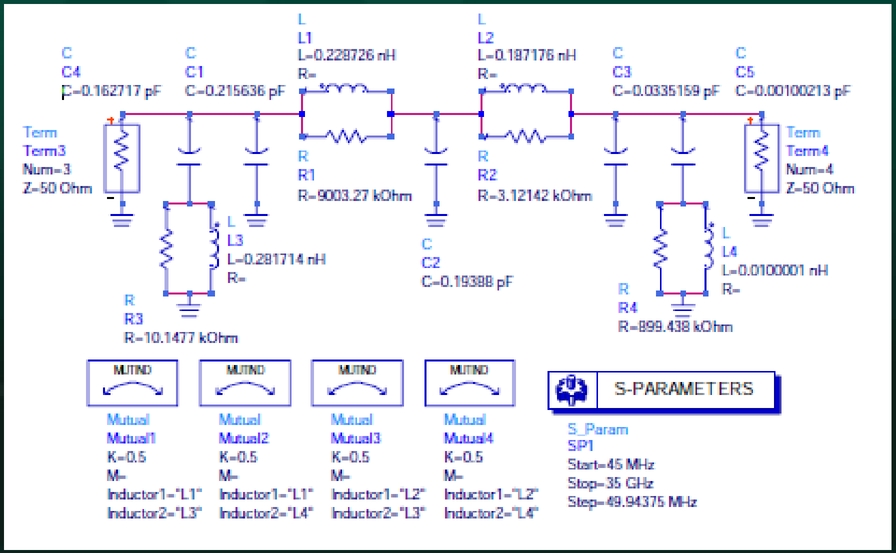
- A survey of the electrical models shows an attempt to attribute inductance to length, capacitance to separation and resistivity to material effects.

- There are many lumped element models used to extract the lumped parameters of spring pins.

Models


Lpartial
P1
P2
Cshunt
Cshunt

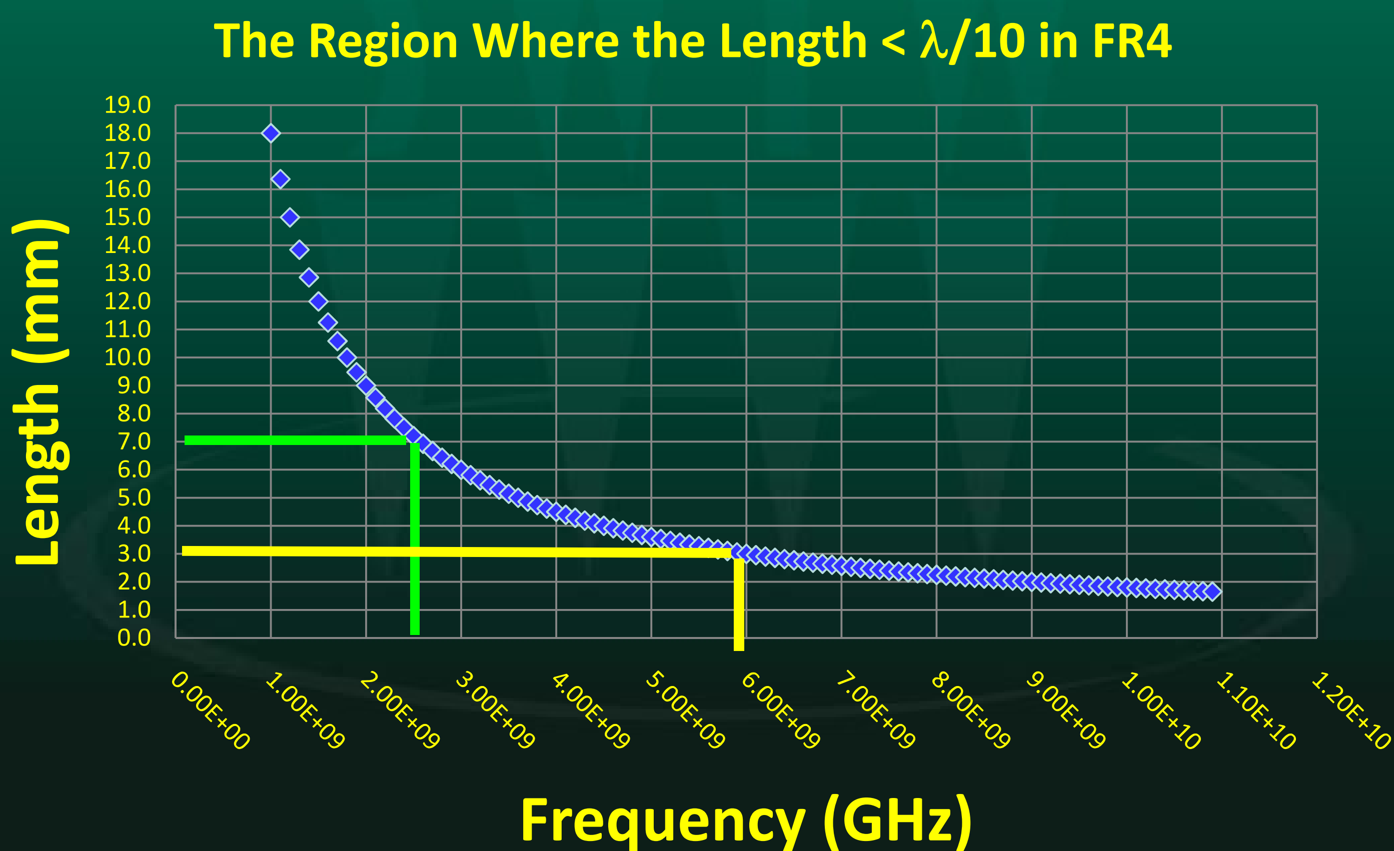

Cshunt_GND
Cshunt_GND
Rskin_effect
Rcontact
Lpartial
Rcontact
P1
P2
Cshunt/2
Mutal
Cshunt/2
P3
P4
Lpartial
Rcontact
Rcontact
Rskin_effect
Cshunt_GND
Cshunt_GND


C
C4
C=0.162717 pF
C
C1
C=0.215636 pF
L
L1
L=0.228726 nH
R=
L
L2
L=0.187176 nH
R=
C
C3
C=0.0335159 pF
C
C5
C=0.00100213 pF
Term
Term3
Num=3
Z=50 Ohm
R
R1
R=9003.27 kOhm
R
R2
R=3.12142 kOhm
Term
Term4
Num=4
Z=50 Ohm
L
L3
L=0.281714 nH
R=
C
C2
C=0.19388 pF
L
L4
L=0.0100001 nH
R=
R
R3
R=10.1477 kOhm
R
R4
R=899.438 kOhm
MUTIND
Mutual
Mutual1
K=0.5
M=
Inductor1="L1"
Inductor2="L3"
MUTIND
Mutual
Mutual2
K=0.5
M=
Inductor1="L1"
Inductor2="L4"
MUTIND
Mutual
Mutual3
K=0.5
M=
Inductor1="L2"
Inductor2="L3"
MUTIND
Mutual
Mutual4
K=0.5
M=
Inductor1="L2"
Inductor2="L4"
S-PARAMETERS
S_Param
SP1
Start=45 MHz
Stop=35 GHz
Step=49.94375 MHz

Techniques For Model Fitting

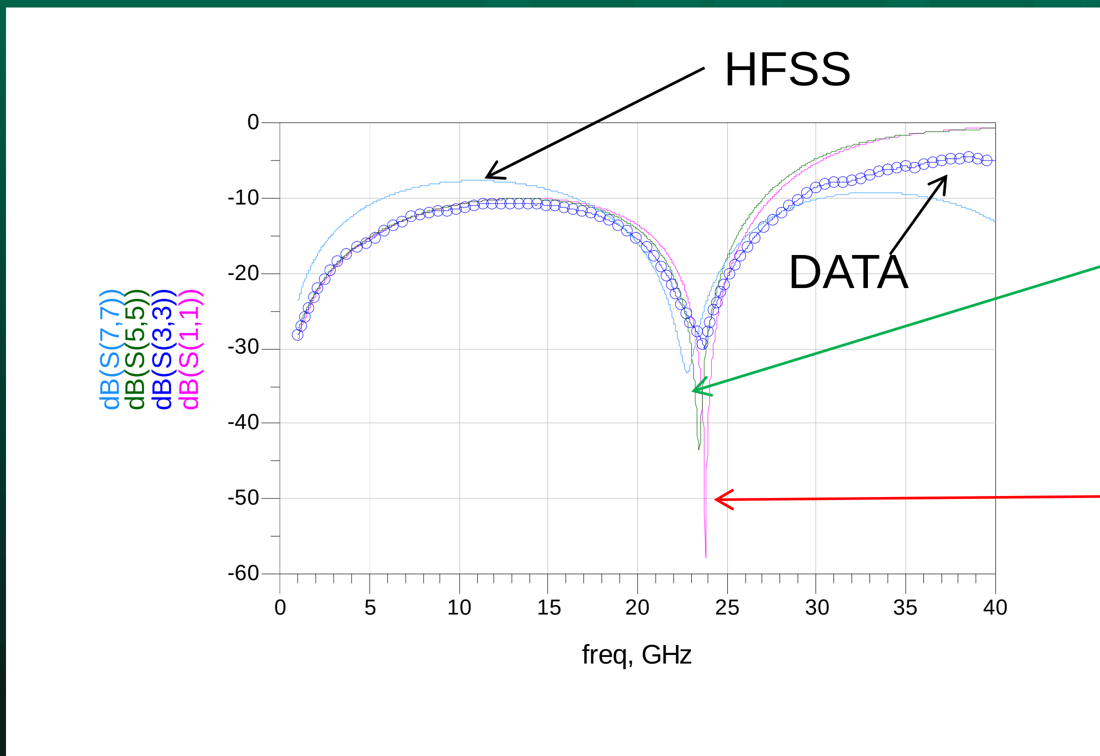
- The model is best fit to the measured s-parameters.
- S_{11} and S_{21} are used to fit the impedance profile.
- The model can be used up to the condition of $L \ll \lambda/10$.

Length << λ/10



The Region Where the Length < λ/10 in FR4
Length (mm)
19.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.00E+00
1.00E+09
2.00E+09
3.00E+09
4.00E+09
5.00E+09
6.00E+09
7.00E+09
8.00E+09
9.00E+09
1.00E+10
1.10E+10
1.20E+10
Frequency (GHz)

Model Output



VAR
Rcontact
Cres=0.1 {t}

VAR
VAR3
Lself=0.48 {t}

VAR
Term1
Cshunt=0.18 {t}

VAR
VAR2
Rskin=1000K

MUTIND
Mutual
Mutual1
K=1
M=3.2e-010 {t}
Inductor1="L1"
Inductor2="L2"

VAR
Rcontact1
Cres1=0.5643 {t}

VAR
VAR4
Lself1=1.5 {t}

VAR
Term7
Cshunt1=0.1847 {t}

VAR
VAR5
Rskin1=1000K

MUTIND
Mutual
Mutual2
K=-1
M=1.338e-009 {t}
Inductor1="L4"
Inductor2="L3"

Pin Placement

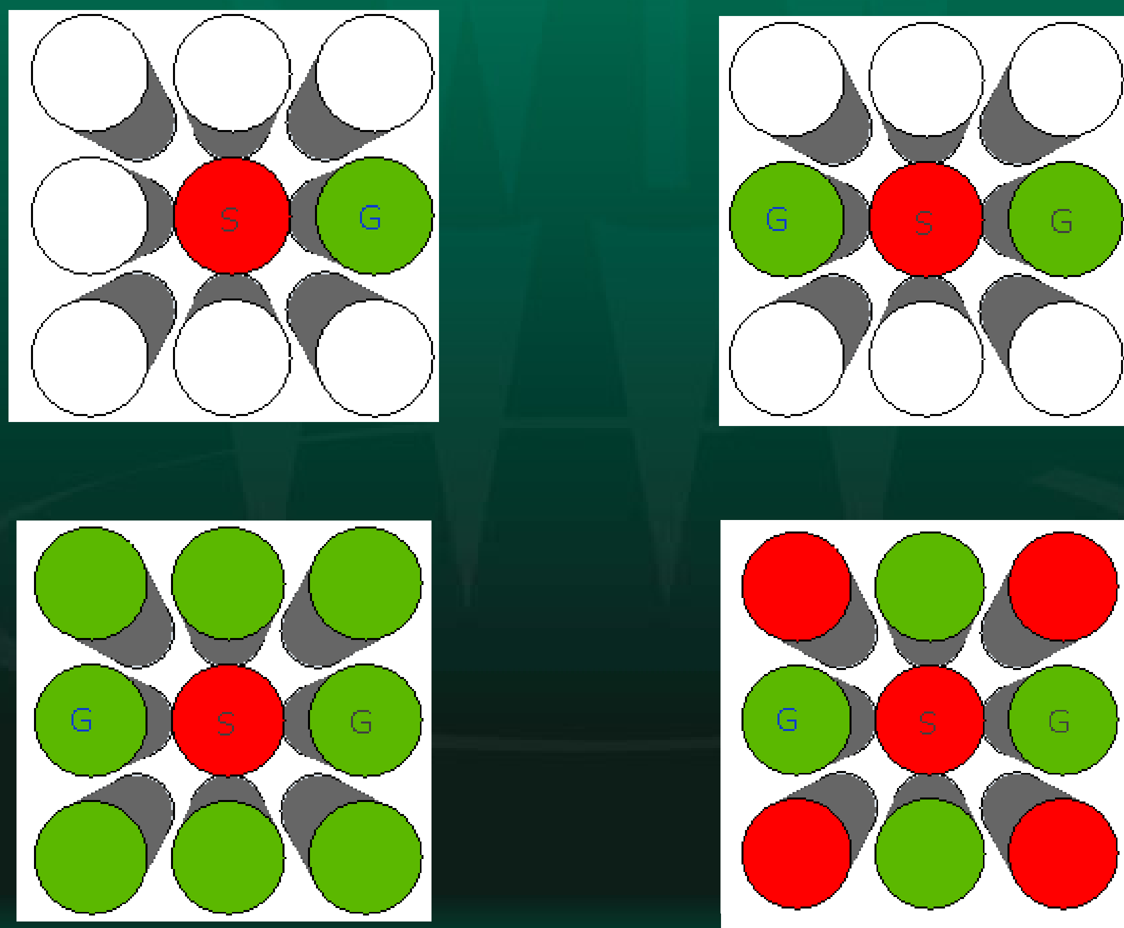
- At frequency the inductance of pins in parallel are not the reciprocal sum of the reciprocals due to the mutal inductances.

$$\frac{1}{L_{Total}} \neq \frac{1}{L_1} + \frac{1}{L_2} + ... + \frac{1}{L_n}$$

$$\frac{1}{L_{Total}} = \frac{1}{(L_1 - \sum_{i \neq 1}^{n} M_i)} + \frac{1}{(L_2 - \sum_{i \neq 2}^{n} M_i)} + ... + \frac{1}{(L_n - \sum_{i \neq n}^{n} M_i)}$$

- Due to the proximity effect current is not shared equally between all pins.

Inductances from a Square Array



Summary

•for optimal **power and ground** performance. partial Inductance should be used as the main metric to compare contact engines

- Mechanically compare the length to radius ratio.
- Beware of stated inductance values in datasheets.

• When **high bandwidth** is desired a matched impedance is required.

- The dielectric constant of the housing becomes important.
- Z is a function of L and C.

Summary

• Inductance should be extracted from an analytical, simulation and measurement.

• Lumped element extractions are accurate when L << λ/10

•The industry should develop a more standarized way to specify and determine WLCSP spring pin lumped element circuit parametrs.

References: Clayton R. Paul, Inductance Loop and Partial

Thank You and Have a Nice Day